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THE PLANT FOOD MATERIALS
IN THE
LEAVES OF FOREST TREES

A DISSERTATION

SUBMITTED TO THE FACULTY

Of the

MASSACHUSETTS AGRICULTURAL COLLEGE

IN CANDIDACY FOR THE DEGREE

OF

MASTER OF SCIENCE

DEPARTMENT OF CHEMISTRY

By

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PREFACE

The investigation of the Plant Food Materials in the Leaves of Trees has formed a part of the work done by the writer in the Chemical Laboratory of the Massachusetts Agricultural College for the degree of Master of Science. This portion of the work was under the supervision of Dr. Ernest Anderson, who proposed the subject and to whom the writer wishes to express his sincere appreciation and indebtedness for the kind assistance and encouragement given him thruout the investigation.

To Dr. Joseph B. Lindsey, Dr. Joseph S. Chamberlain and Dr. Charles A. Peters, members of this department, are due many thanks for their valuable suggestions, advice, and criticisms from time to time during the work.

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To Mr. Charles R. Green, librarian of the College, many thanks are due for his very kind services in obtaining references from the various libraries in Massachusetts and outside of the State, without which the writer would have been unable to collect and record many of the references cited in this investigation.

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INTRODUCTION

1. Purpose of the Investigation.

This work was undertaken for the purpose of investigating the plant food constituents of the leaves of three typical New England forest trees at the beginning of their activity in the spring and practically at the end of their growth in the fall; to observe the difference in content of these materials in the leaves taken from the branches nearest the soil and those from the very top of the tree; to observe the varying content in the leaves of the same species of tree grown upon different soil type; also to estimate the manurial value of leaves.

2. Review of the Literature.

The numerous factors entering into the variations in the plant food content of various forest leaves make it extremely difficult to draw any absolute conclusions as to the direct causes of the variations. The literature upon this phase of the investigation will bring out these various factors and the results assigned as being directly caused by these factors.

As early as 1795 the Earl of Dundonald[1] (1) arrived at some fundamental conclusions in regard to the effect of trees upon the soil. After careful investigation the author showed that plants grown upon the same soil and upon different soils had varying amounts of their characteristic constituents. As different parts of a plant require different proportions of these essential elements, he concluded the plants must draw upon these substances at different periods of their growth.

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[1] Reference is made by number to "Literature cited", p. 52.

On the analysis of the oat plant in an unripe state and in the ripe condition Norton (2) shows the varying amount of the different constituents of the leaves in weekly periods from the beginning of growth until it is harvested. In the dry material of the oat leaves the ash increased from 10.83% to a maximum of 22.13%, and during the ripening period the percentage ash decreased, which was assigned as being due to some of the constituents being carried back into the stalk, which shows an increase at the ripening period. The potash and phosphoric acid content exhibited a decrease thruout the growing season, while the silica content showed a very marked increase. With the ripe plant Norton noticed that the composition of the leaf varied with the soil, the manure, variety of oat, and the position of the leaf upon the plant.

Michael (3) in her investigations upon the comparative chemistry of higher and lower plants observed that the ash constituents of a plant increased from the roots upward to the leaves and also found this general principle to be true in the entire plant kingdom.

The results of E. Wolff (4) and Staffel (5) in their separate work upon the leaves of the common Horse Chestnut

(Aesculus Hippocastanum (L.) showed a decrease in the percentage of potash and phosphoric acid in fall leaves compared to those in the spring. Lime and silicic acid exhibited a large increase. The analytical results of the two authors indicated a large variation, but this may be accounted for by the fact that the leaves were collected from widely different soil types in different sections of Germany and at a different time.

Staffel (6) also investigated the constituents of the walnut leaves (Juglans regis) and here again the same general relations as to the contents hold.

In 100 parts of ash

	K_2O	CaO	P_2O_5	SiO_2
Chestnut leaves May 6, 1850	49.32	13.17	24.40	1.76
" " September 1, 1849	19.57	40.48	8.22	13.91
Walnut leaves May 31, 1850	42.70	26.86	21.12	1.21
" " August 27, 1849	26.57	53.65	4.04	2.02

Both samples were collected in Jena, Germany.

Wittstein (7), Zoeller (8), Fresenius (9), Wicke and Henrici (10) investigated the constituents of the leaves of the beech tree (Fagus sylvatica) and their results in the table following show the same relations between the mineral ingredients.

Analyst		Date	K_2O	CaO	P_2O_5	SiO_2
Wittstein	Beech leaves	No date given	20.56	25.58	12.00	28.50
	" "	May 16, 1861	42.11	13.83	32.43	1.62
	" "	July 18, 1861	17.15	42.34	8.29	21.39
Ph. Zoeller	" "	Oct. 15, 1861	7.15	50.66	5.13	30.50
(Tree about 20-30	" "	Nov. 1860	1.33	45.72	2.61	32.64
years old)	" "	Nov. 1862	5.53	46.27	3.79	32.34
C. Fresenius	Fresh leaves in August		20.87	32.82	7.86	10.17
Wicke & Henrici	Dried leaves (dead leaves)		1.96	61.05	1.18	26.70

Neubauer (11), Wicke and Henrici (12) took fresh leaves of the common oak (Quercus Robur) in August and dead leaves from the same tree in the fall, and found a large decrease in the potash and phosphoric acid and an increase in lime and silicic acid.

Wittstein (13), J. Schröder (14) and A. Beyer (15) examined the leaves of the white birch (Betula alba L.) with similar results.

Reichardt (16) worked upon the leaves of the white willow (Salix alba L var vitellina L.) arriving at the same conclusions.

Krutzsch (17) and Karmrodt (18) used the needles of the Scotch pine (Pinus silvestris L.) and the spruce fir (Pinus albies L.) (Albies excelsa Link) for their investigation of the constituents; Schulze (19) investigated the needles of the Scotch pine and also of the silver fir (Pinus Picea) (Albies pectinata). The potash and phosphoric acid content in the needles of these various pines was considerably less than in the leaves of other trees, while the silicic acid and lime content in the majority of cases was higher than that of other tree leaves.

The Influence of Different Factors upon the Composition of Leaves.

Succeeding this early period of invsetigation upon the composition of leaves from various forest trees, numerous researches were published in which the investigators endeavored to show the variations due to the period of development of the leaves, to their height from sea level, to the effect of soil, and to the development of the tree itself.

Rissmüller (20) studied the variations in the several inorganic constituents of the leaves of a beech tree (Fagus sylvatica) growing in the botanical gardens at Munich at different periods in their development. The tree had never borne fruit, which factor did not enter into the problem. The leaves were collected every month from May to the middle of November, and his results showed a decrease of potash and phosphoric acid every month, potash dropping from 31.23% in May to 5.78 in November, while the phosphoric acid dropped from 21.27% to 1.08% in the same period. On the other hand, lime and silicic acid showed an increased percentage, the former increasing from 14.96% in May to 32.95% in November, and the latter going from 1.87% to 26.32% in the same time. The other inorganic constituents showed only a very slight variation thruout the period of development.

Dulk (21) investigated the contents of beech leaves collected from a tree in the botanical gardens at Hohenheim. His results agree in general with those of Rissmüller, although they do not show such a wide variation from the early to the last stage of growth. There was, however, one exception which Dulk explained as possibly being due to the weather conditions, which were: "July and August warm and dry, September cold and moist, October warmer." His results show a decrease in potash and phosphoric acid, as growth proceeded until October when a very marked increase was noted, followed by a drop in November noticeably below the results obtained in September. In the case of silicic acid and lime, instead of a constant increase there was a decrease in October.

Weber and Ebermayer (22) in 1872 working together obtained practically identical data with the leaves of beech trees grown in the forest at Aschaffenburg.

Weber (23) obtained very marked variations in the content of beech leaves grown at different heights from sea level, but since they were grown on different soil types, under varying weather conditions and were collected from trees at different ages, it is practically impossible to attribute the variations entirely to the change in height from sea level.

Weber (24), and later Weber and Ebermayer (25) investigated the needles of the fir tree (Pinus albies) at different heights from sea level.

The height above sea level influences the composition of tree leaves according to Dr. Ebermayer (26). His results indicate a decrease in total ash content, as well as in phosphoric acid, as elevation increases. He concludes that the ash of pine and beech leaves from trees in the lowlands is five times richer in phosphoric acid than the ash in those from the mountains, and therefore the removal of litter in the lowlands is more hurtful than on the mountains.

In order to show the variations in the leaves of different species of tree grown upon the same soil and as nearly as possible under the same natural conditions, Henry (27) analyzed leaves from various trees, the results of which are given in the following table:-

Common Name	Botanical Name	Percentage content in leaf ash K_2O %	 CaO %	 P_2O_5 %	 SiO_2 %
Mountain ash	Sorbus tormintalis	24.49	42.68	7.01	2.34
Wild apple	Malus acerba	24.75	53.39	6.71	2.31
Hazel nut	Corylus avellana	18.32	52.77	7.92	5.79
High elm	Ulmus montana	23.67	29.31	7.63	19.91
Maple	Acer campestre	25.41	30.89	9.56	11.07
Beech	Fagus sylvatica	21.83	44.37	7.83	10.56
Oak	Quercus Robur	22.39	47.04	12.39	5.21
Ash	Fraxirmus excelsior	18.70	39.45	22.62	2.63

The data obtained by Grandeau and Fliche (28) in their investigations upon the leaves of three species of trees grown upon the same soil and taken at different stages in their development showed the same general characteristics with but one exception. The leaves were collected from the locust (Robinia pseudacacia (Kugelakazie)), the birch (Betula alba) and the chestnut (Castanie vulgarie). Instead of showing an increase in silicic acid as development proceeded, the leaves of the locust tree showed a decrease. As to the exact cause of this exception the investigators did not advance any explanation.

Since the needles of the pine tree remain attached to the branches for a period of years, the factor of age may be considered as having an influence upon the inorganic composition. It is doubtful, however, if the entire change in composition is due to this factor.

The researches of Schröder (29) and Dulk (30) with needles of different ages from the Scotch pine (Pinus sylvestris) showed that the younger portions had the greatest percentage of potash and phosphoric acid and the smallest percentage of lime and silicic acid.

Grandeau and Fliche (31) found that the needles of the black pine (Pinus austriaca) (Pinus laricio austriaca Endl) had the same characteristics as to composition as did those of the Scotch fir. The remarkable influence of the soil upon the mineral constituents can be noted from the work of Grandeau and Fliche. The trees under observation grew in a very rich lime soil and the percentage of lime in the needles was nearly twice that obtained in other needles or leaves, going as high as 70% in the three and four year old needles.

B. Corenioinder (32) in his experiments with the leaves of Cerasus Laurocerasus (Prunus L.) found nitrogenous matter most abundant in young leaves, decreasing in amount as the leaves grew older. He found the same true of the phosphoric acid content but in the case of the ash and lime the reverse held true.

Bechi (33), Grandeau and Fliche (34) obtained results upon the leaves of the chestnut tree (Castanea vulgaris) which do not show anything different from what has been mentioned in previous investigations.

The following table from Wolff (35) shows not only the average composition of the inorganic constituents of the leaves of the different trees, but also the means and extremes of composition as indicated by the small figures. The results are from the analyses of the ash of the leaves.

	K_2O	CaO	P_2O_5	SiO_2
Beech leaves - August	27.3-14.3 20.17	41.9-18.3 29.12	12.6-5.8 8.38	47.9-14.2 28.65
" " - November	20.6-1.3 7.69	61.1-25.2 40.65	12.1-1.2 5.70	51.3-22.6 34.55
Oak leaves - August	33.14	26.09	12.19	4.41
" " - dead	3.35	48.63	8.08	30.95
Fir needles on tree	42.2-18. 29.97	36.5-12.7 23.85	24.8-9.2 16.00	6.5-.9 3.36
Black pine needles (very young)	26.3-19.1 21.84	44.3-15.5 29.28	27.9-12.0 18.03	3.8-1.3 2.69
" " " (1 year old)	12.8-9.5 11.10	60.7-53.5 56.58	13.1-8.2 11.47	3.9-2.6 3.37
" " " (2 " ")	12.6-3.3 6.50	63.9-53.4 59.85	11.6-8.7 10.00	4.9-1.9 3.52
" " " (3-4 " ")	5.0-0.0 1.60	70.5-63.4 66.27	10.5-5.9 8.57	6.3-2.2 4.02
Larch needles on tree	28.9-15.8 22.75	39.1-14.5 26.44	23.7-8.8 16.24	24.1-4.2 16.79
Pine " " "	44.2-29.6 29.61	88.0-10.4 20.47	22.2-9.5 14.73	46.0-4.1 20.17
Leaves of trees in general - May	32.8-25.3 30.19	39.6-18.4 34.63	21.2-15.8 18.43	3.7-1.4 2.11
" " " " " - Sept.	17.0-6.6 10.74	73.0-39.1 49.09	11.0-5.3 7.86	2.8-2.0 2.37
" " " " " - Oct.	11.8-2.9 7.12	72.-44.1 54.08	8.6-1.9 5.67	4.7-1.7 2.80

Schulze and Schutz (36) investigated the variations of the materials in the leaves of a box elder (Acer Negundo L.) from the spring until autumn, and also endeavored to show the influence of day light in causing variations. The leaves were collected in monthly periods between 5 - 6:30 A.M. and 6 - 6:30 P.M. The constituents determined included total phosphoric acid, potash and nitrogen.

The results showed a marked decrease in phosphoric acid and nitrogen, and a very slight decrease in potash, while the lime content[+] increased the older the leaves became. The content of potash, phosphoric acid and nitrogen was higher in the evening than in the morning, which seemed to indicate a stronger flow of mineral matter during the day.

Date	Time	P_2O_5	K_2O	N.
May 7	A.M.	1.500	3.113	4.304
"	P.M.	1.697	3.396	4.506
June 6	A.M.	.801	3.316	3.906
"	P.M.	.846	3.433	3.983
July 5	A.M.	.705	2.698	4.068
"	P.M.	.753	2.824	4.141
August 2	A.M.	.580	2.664	3.745
"	P.M.	.640	2.567	3.751
September 25	A.M.	.333	2.696	2.110
"	P.M.	.374	2.941	2.139

[+] No data was given for lime (CaO) except that a statement was made similar to one above.

In 1907 and 1908 Richter (37) examined the leaves of different fruit trees which were of the same age, had received the same amount of manure, and were grown upon the same soil very near to each other. The leaves used for the investigation were: Cherry (Doktorkirsche and Spanische Gloskirsche); Pear (Hertrichs Bergamolte, Clairgeaus Winterbutterbirne, and Napoleons Winterbutterbirne); Apple (Graf Nostiltz and Linous Pipping); Plum (Frühe vom Buhlertal, Reinclande and Italienische Zwetsche). The different varieties of the same species showed marked variations in the nitrogen content, the other constituents, however, varied very little. The leaves of the plum trees showed a greater content in nitrogen, phosphoric acid, lime and potash than the others. The phosphoric acid content in the four fruit tree leaves showed the greatest constancy.

In 1908 the same investigator studied the variations thruout the development of the leaves of the plum, cherry, pear and apple trees. Nitrogen showed a continual decrease containing at the end one-fourth to one-fifth of the original content. The amount of lime increased in each of the several species of fruit trees. The potash content decreased gradually in the pear and apple, remained about the same in the cherry, and in the case of the plum it more than doubled in amount. The same characteristic increase of the potash was observed in other varieties of plum, and for this reason Richter considered the autumn leaves of this tree valuable manure, the potash amounting to nearly 6% of the dry material.

The phosphoric acid content decreased steadily in all species. About the time the fruit began to ripen the nitrogen and phosphoric acid manifested a very rapid decrease, which seemed to indicate a relation between the nitrogen and phosphoric acid content and the development of fruit.

In an endeavor to show that there is an emptying of constituents in autumn leaves, Richter used the leaves of the same fruit trees, collecting them every month, the last collection being about the last of October just as the colored leaves were about to fall. In all cases the nitrogen and phosphoric acid decreased, but the potash and lime did not show any regularity, increasing in some cases and decreasing in others. He concluded that the backflow of materials from the leaves seemed to be influenced by the weather. If the autumn was warm there was a backflow, but if cold there was not time for a backflow to take place.

The leaves of five varieties of apple trees were investigated by F. T. Schutt (38) and his averages showed a smaller content of nitrogen and phosphoric acid in the fall as compared with the spring, whereas the total ash and potash showed a slight increase in amount.

A study of the changes in the mineral matter in the withered autumn leaves of the beech, oak and hazel trees was undertaken by Raumann (39). The leaves were analyzed when green and also when colored, and with but one exception a decrease was noted in the percentage content of potash, phosphoric acid and nitrogen in the colored leaves, while the percentage content of lime and silicic acid increased. The exception was in the case of potash in the beech, which gave a higher content in the colored leaf than in the green leaf. This exception, together with the fact that the potash content varied very little, may be due to the fact that the trees under examination grew in a rich potash soil, and hence was not needed by the branches, and therefore the return was only moderate or not at all.

A more detailed investigation was carried out with leaves taken from the following trees: Maple (Acer platanoides L.), Birch (Betula alba L.), Oak (Quercus pedunculata Ehr), and Wild acacia (Robinia pseudacacia L.) As in previous investigation, nitrogen, phosphoric acid and potash showed a smaller percentage content in the mature leaves as compared with the green leaves, while an increase was observed in the lime and silicic acid. The strongest return was in the content of nitrogen, and as there also occurred a strong return of sulphate (SO_4), the cause of this phenomenon may be traced to the large movement of albumin substance from the dying leaves to the stem and branches of the tree. An early frost checks further metabolism, thus preventing the return of albumin substance and resulting in a great loss to the tree.

Tollens and Tucker (40) found a rapid change during the coloring of the leaves of the beech tree, and their results were analogous to those of Ramann.

Schröder (41) from his work upon frozen beech leaves concluded that during the withering potash and phosphoric acid returned to the stem, while the protein material, as indicated by the nitrogen and sulphate determinations, remained in the leaf and was thus a total loss to the tree.

Ramann (42), in order to confirm the retention of the mineral matter with the freezing of leaves, analyzed birch leaves which had been frozen and also some which had not been affected by the frost from the same tree. The frozen leaves had turned black and had dried up and both samples of leaves were collected the next day after the frost. The analysis shows clearly the variations:

	K_2O	CaO	P_2O	SO_3	N
Uninjured leaves	10.34	23.73	3.02	2.19	19.67
Dead from frost	7.45	29.14	1.61	2.06	20.16
Difference	-2.89	+5.41	-1.4	-.13	+.49

As has been brought out in previous work, the nitrogen and sulphur content decreases rapidly with the regular dying of the leaf organs, indicating that these substances return to the tree. The results showed no such decrease in frozen leaves and Ramann concluded that the albumin content was a total loss to the tree by the freezing of its leaves.

Potash and phosphoric acid showed a decrease and lime an increase in the frozen leaves, but the backflow did not amount to as much as with the normal death of the leaves. Another significant result of this investigation was the indication of the speed of the migration of the various substances from the leaves to the tree and vice versa.

Ramann and Bauer (43) in their investigations, concerning the content of many species of very young trees thruout the entire period of vegetation, arrived at the following conclusions:

(1) The leafing out of the leaves of the trees in spring results, in the case of foliage trees, at the expense of the reserved material in the plant; with evergreen trees, however, the drain upon the reserve material cannot be sharply detected because of the assimilation of material from the soil at a very early period in the spring.

(2) During the leafing out a considerable amount of plant materials, in the case of young trees, is dissolved and used up for the production of the young shoots.

(3) The formation of sucker growths make similar demands upon the reserved plant foods as do the spring shoots.

(4) The withdrawal of plant food material from the soil takes place at different times according to the species of tree.

(5) The individual food nutrients are taken up at various stages in the growth of the tree.

These last two conclusions are the practical reasons for the necessity of mixed woodlands in order to maintain soil efficiency and the continued success of a rich producing forest.

Ramann (44), in a very interesting and extremely accurate series of investigations, endeavored to show the variations of mineral matter in tree leaves during the night and the day. Such variations were not noticeable except in the case of the lime, which showed the greater content at night. It is frequently assumed that the percentage of lime increases as growth proceeds; hence, the lime content of the leaves would be greater at night. To show this was not the true cause of the variations, Ramann proved by analyses that the day content of leaves taken several days later was lower than the night content of leaves collected several days previous.

The investigator considered that this relation was produced in connection with the transport of the assimilation products which is stronger in the day due to the formation of organic matter. The trees under consideration were the beech, oak, hazel, platane, and maple (Acer dasycaspum).

Otto and Kooper (45) worked upon the variations of nitrogen compounde in the leaves of deciduous trees during the night and the day. As nitrogen was an indication of albumin material, the investigation showed that the decomposition of the albumin matter was greater at night than the new formation of albumin matter. The leaves were taken from the same tree at 6 o'clock at night and at 6 o'clock in the morning, and in the investigation upon Syringa vulgaris, Sambucus nigra, Phlox Drumondi, Philadelphus coronarius, and aesculus hippocastanum, the nitrogen content was in every case higher in the evening leaves than those collected in the morning. Otto and Kooper concluded that there must take place a transportation of nitrogenous material in the night to other portions of the tree. As very little nitric acid was found in the leaves, the investigators assumed that the increased nitrogen content during the day was due to the taking up of atmospheric nitrogen in a similar manner, as is carbon dioxide. They found that the nitrogen content decreased gradually and continuously thruout the growth of the leaves, which had been proved for Humulus Lupulus by Fruwirth and Zielstorff (46). Otto and Kooper concluded that part of the nitrogen compounds were transported to the reserve portions of the plant and part to aid in the formation of fruit.

Swziki (47) in his investigations also came to the conclusion that the proteids formed during the day were decomposed at night and transported to other sections of the plant.

Frank and Otto (48) also found in the green leaves of the Lupinus lutens, Carnur carvi, Vitis vinifera, Cannabis sativa, Brassica oleracea, Lathyrus sylvestric, Medicago sativa, Trifolium pratense, more nitrogen in the evening than on the next morning, and concluded that the nitrogen was transported in the form of asparagin to other portions of the plant, and further that the nitrogen came from the air.

The sources of nitrogen in the leaves of trees and plants have lead to many investigations, especially as to whether the nitrogen came from the air or the soil. Boussingault (49) in all his experiments conducted during the last part of the 19th century rejected the views that trees were capable of assimilating nitrogen from the air. Ville (50), on the other hand, took the opposite view. Frank (51) in 1885 arrived at opposite conclusions from Boussingault, but his experiments were carried out with legumes. Hellriegel (52) in 1886, working with both legumes and non-legumes, proved conclusively that the assimilation of atmospheric nitrogen was only possible with legumes, and then only if they lived in symbiosis with their root tubercle bacteria.

Frank and Otto (53), from their investigations with tree leaves, contended that the assimilation of atmospheric nitrogen by tree leaves was probable.

Prazmowski (54), Schlösing and Laurent (55), and Kossowitsch (56) came to similar results as Hellriegel.

Frank (57), as a result of further investigations, still maintained that legumes could assimilate free nitrogen without being in symbiosis with nodule bacteria and also that non-leguminous plants assimilated free nitrogen.

Peterman and Liebscher (58), Stocklasa (59), and Jameson (60) arrived at similar conclusions in their investigations.

Otto and Kooper (61) worked with non-leguminous plants in an endeavor to ascertain to what degree the leaves of higher plants were capable of nitrogen assimilation. They sought to determine whether or not organic nitrogenous compounds can be formed from the free nitrogen of the air together with carbon dioxide and water with the assistance of light and heat, in a similar manner to the transformation of carbon dioxide of the air to organic matter. These same investigators (62) showed that there was a transfer of nitrogenous material during the night from the leaves to the branches. Leaves were taken from Aesculus hippocastanum in the morning, a portion analyzed for nitrogen content and another portion placed in distilled water under as natural conditions as possible. At night these leaves were then analyzed. Their results show a very slight decrease in the percentage of nitrogen in the evening leaves and they concluded that an assimilation of free nitrogen of the air by the leaves was very improbable, although it might be possible. Other conclusions were that the nitrogen content was less than that of the previous year, and also that a marked decrease took place as vegetation proceeds. The decrease in nitrogen in the evening may be due to the relative carbohydrate increase in the leaves during the day, which would naturally make the percentage of nitrogen content lower.

In an interesting piece of work G. André (63) compares the phosphoric acid, potassium and nitrogen content in the early development of a perennial and of an annual plant and its relation to the content of the seed. In the case of an annual plant (scarlet runner) André (64) showed that when the plantule attained the same weight (18 days) as the seed, the loss in dry matter of the cotyledons rose to 78% and the losses in phosphoric acid, potash and nitrogen rose respectively to 87%, 81% and 85%. In the case of the chestnut the facts are of the same order, the loss in dry matter rose to 73.7% and the losses in phosphoric acid, potash and nitrogen rose to 81.2%, 72.8% and 82.3%. The chestnut plant attained the same weight as that of the seed in 4 1/2 months. From these two plants, the mineral elements and nitrogenous compounds seem to contribute, with varying velocities, but in the same proportions, to the building up of living plants There is an increased amount of phosphoric acid and potash in the roots of the walnut tree during the first and second years, and in the first year in the case of the horse chestnut tree, which fact seems to indicate very well the function of the root as a reserve organ.

André's (65) investigation of the different forms of nitrogen in the chestnut leaf thruout the period of growth showed conclusively that the total nitrogen decreased as vegetation increased, that the soluble amide nitrogen decreased rapidly at the time of the fecundation of the flowers and continued to migrate from the leaves until the period of fecundation is over, when it again accumulates in the leaf. Thruout the period of growth there was found only slight traces of nitric nitrogen. Since there is very little nitric nitrogen

André believes it highly probable that the original source of nitrogen was organic in nature, which was rendered available by the mycorhiza covering the roots.

Upon investigating the phosphoric acid (H_3PO_4) and nitrogen content in the leaves of the chestnut tree, André (66) showed that a noticeable decrease of phosphoric acid took place about the middle of July, which corresponded to the period of nitrogen migration towards the floral organs. The soluble phosphates were abundant in the young leaves but decreased noticeably from July 15 to August 17. The formation of lecithines and nucleines required soluble phosphates for their use, and as the maximum production of these two organic phosphorus compounds was reached about the middle of July, the soluble phosphates were not required later, and consequently diminished rapidly. The contents of the leaves in phosphatides was highest during florescence and declined during vegetation.

André added to the accumulative data that the content of magnesium oxide (MgO) and lime (CaO) of the ash of leaves of the chestnut increase, and the potash and phosphoric acid decrease with the advance of vegetation. The ash content of the chestnut leaves exhibited only slight variations threout the period of growth as compared to the leaves of annual plants. Another significant variation pointed out by André was the very slight amounts of silica in the chestnut leaves in the periods of growth as compared to other perennial and annual plant leaves.

In order to determine definitely whether an annual plant whose activity lasted only a short time conserved all the mineral matter which it took up, André (67) experimented with the common pink. Other investigators (68) had found that the plant gave off a part of its mineral matter at certain periods in the development of the plant. André found, on the contrary, that no mineral matter left the plant thruout its existence.

In two later papers André (69) confirmed his past work with the pink plant and enlarged his results by showing the distribution of the various important materials at different periods of growth. A table of André's results will undoubtedly illustrate the distribution of total ash, nitrogen, phosphoric acid and potash much better than words.

Date of collection of sample	Weight of 100 dry organs in grams	Total ash in 100 dry organs in grams	H_3PO_4 in 100 dry organs in grams	K_2O in 100 dry organs in grams	N in 100 dry organs in grams
		Roots			
June 13, 1910	32.85	5.821	.6208	2.3144	1.0019
June 28, 1910 (Formation of floral buds)	123.12	22.0359	2.6823	7.9392	3.3796
July 13, 1910 (Florescence)	416.00	40.2688	5.3664	13.6864	4.7424
August 9, 1910 (Fruit nearly ripe)	545.16	40.1782	3.4890	12.7567	3.7070
August 23, 1910 (Complete maturity)	655.40	51.7110	2.9493	16.0573	5.6366
		Branches			
June 13, 1910	57.85	14.1096	1.1974	4.9924	1.6892
June 28, 1910 (Formation of floral buds)	698.43	90.6562	11.5939	41.0676	12.5717
July 13, 1910 (Florescence)	1787.20	173.3584	33.7780	66.6625	20.7315
August 9, 1910 (Fruit nearly ripe)	2385.20	170.3032	19.5586	60.3455	21.2282
August 23, 1910 (Complete maturity)	2947.30	229.8894	14.1417	81.0507	26.5257
		Leaves			
June 13, 1910	287.55	66.7524	5.2676	19.3535	14.9394
June 28, 1910 (Formation of floral buds)	791.25	169.7263	10.9963	39.7205	29.6718
July 13, 1910 (Florescence)	1134.84	301.300	22.6968	52.8835	36.6553
August 9, 1910 (Fruit nearly ripe)	1367.28	436.4357	21.1928	32.2678	31.9943
August 23, 1910 (Complete maturity)	1269.85	413.0822	17.2699	17.5239	28.5716
		Fruit or Seed			
June 13, 1910	-----	-----	-----	-----	-----
June 28, 1910 (Formation of floral buds)	-----	-----	-----	-----	-----
July 13, 1910 (Florescence)	343.88	29.1954	6.3273	11.7263	11.4512
August 9, 1910 (Fruit nearly ripe)	1922.84	153.6349	46.1481	38.4568	61.3385
August 23, 1910 (Complete maturity)	2180.80	193.0008	52.9934	45.5787	65.8601

The migration and distribution of ash, potash, phosphoric acid and nitrogen in the pink plant thruout its growth may be easily observed by a careful study of the foregoing table. André in his conclusion, stated that there is no loss of mineral matter or nitrogen during the growth of the pink plant. The total ash showed a regular increase in all the various organs as the period of growth increased. The same relation held in the case of the dry matter with one exception, notably in the last sample taken of the leaves where a decrease was observed. André claimed this loss was due to a large extent to a respiratory loss. From the results given in the table it may be seen that the nitrogen content in the roots of the plant increases up to July 13 (period of florescence) when it diminishes until on August 23 an increase is observed which attained the maximum weight at that date. It probably is true that the decrease during the period from July 13 to August 9 was due directly to some of the material being withdrawn to supply the floral organs which showed a very large increase during this same period. In the branches the nitrogen content increases thruout the period of vegetation. The nitrogen in the leaves shows an increase until July 13, after which it gradually diminishes. The withdrawal of nitrogen from the leaves during this period is undoubtedly due to that element going towards the supply of nitrogen for the fruit. The nitrogen content in the fruit rapidly increased while the fruit is maturing.

The migration of phosphoric acid is more regular than that of nitrogen or potash. Phosphoric acid increases regularly up to July 13 in the roots, branches and leaves, after which date there is a rapid decrease. The phosphoric acid content increases continuously from July 13 to complete maturity of the fruit.

In the case of the potash, the variations in the different organs of the plant follow very closely those of nitrogen.

Another general rule which may be noted from the table is the fact that the younger the plant the higher is the percentage amount of nitrogen, potash and phosphoric acid.

In the case of the barley plant, André (70) found that it did not lose in the course of its vegetation either nitrogen, phosphoric acid, sulfur, lime or magnesium, but sustained a noticeable loss of sodium and potassium between the period of florescence and maturation.

The loss of alkalies in the cereals is a generally accepted fact.

With three more annual plants, each of a different species, namely, the spurrey (Spargula arveusis), the flax (Linum usitatissimum) and cameline (Cameline sativa), André(71) found that no loss of mineral matter or total nitrogen took place.

To ascertain the relative amount of mineral matter and nitrogen fallen leaves would return to the soil by the action of water, André (72) immersed leaves of a chestnut tree at different periods of growth in water for a month, determining the amount of nitrogen, phosphoric acid (H_3PO_4), sulphate (SO_3), lime, magnesium oxide and potash before and after immersion. The table below shows the percentage of the several ingredients that has diffused during the period of a month:-

Date of Collection	Total N % Dry basis	H_3PO_4 %	Total sulphur SO_3 %	CaO %	MgO %	K_2O %
June 2, 1912	6.19	64.84	58.80	20.03	50.72	95.39
July 29, 1912	3.17	69.54	---	---	---	89.10
September 25, 1912	6.30	63.48	68.25	21.92	40.32	87.93

From an examination of the figures potash shows the greatest exosmosis, and nitrogen the lowest. The phosphoric acid, sulphur and potash evidently exist in the leaves thruout their growth in a form fairly soluble in water which practically becomes available soon after the death of the leaves. The nitrogen and lime exist probably in a complex organic formation which requires the breaking down of the structure of the leaves through the agency of decay before the material can become available.

Comparative experiments by Tucker and Tollens (73) with leaves of the plane tree ptotected from rain and others non-protected, showed that rain has little, if any, washing out action on the food materials of the leaves.

Dr. Josef Seissl (74), in a very interesting and significant investigation concerning the total and organic phosphoric acid content in the leaves of horse chestnut, maple (Acer pseudoplantinses), Quercus Robur, Lilac Philadelphus, Polygonum sachalmene, found; first, that the total phosphoric acid was highest at the beginning of growth and thereafter showed a gradual decrease thruout the vegetative period; second, that the organic phosphoric acid in the leaves reaches its maximum content at a time when the process of assimilation is at its highest, and that this period seems to coincide with the time when the most active building of green coloring material is going on in the plant cells; third, that the organic phosphoric acid found reaches its minimum content at the conclusion of assimilatory action which coincides to that period when the leaves are colored; fourth, that as the physiological processes are intensified in the leaf, so does the organic phosphoric acid respond readily, thus increasing the supply for the demand; fifth, that the demand for organic phosphoric acid results in a greater intake of inorganic phosphorus from the soil, which must undergo a process of reduction in the plant for the formation of the organic phosphoric acid.

Seissel (75) in another investigation concerning the content of leaves during different vegetative periods endeavored to bring out the relation of magnesium oxide to calcium oxide. In all cases where green plants were used the calcium oxide was much higher than that of magnesium oxide, while in plants which were not green the reverse relation was evident.

Dunnington (76) determined the various inorganic materials in nearly a dozen varieties of weeds, the complete analysis of which may be found in the reference.

In an attempt to ascertain the manurial requirements of plants by their analyses, von Seelhorst, Behn and Welms (77) found that the composition of plants was greatly affected by various chemical conditions, and therefore concluded that this method was impractical.

In connection with the study of the composition of plants and their various parts a large amount of investigational work has been done upon important farm crops with various objects in view. As the next few references have no direct bearing upon this present investigation, I shall cite only the important articles as worthy of study to those interested in this phase of work.+

Literature on the Use and Value of Leaves as a Manure.

In his extensive study of blueberry culture, Coville (82) made many interesting and practical investigations of the various factors affecting blueberry culture. One of the

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+ Forbes, Whittier and Collison (78), having under consideration the relation of the food values of grasses to stock raising, made a study of the mineral nutrients in blue grass grown in various sections of Ohio and Kentucky.

A very comprehensive study of environmental influences upon the chemical composition of wheat along with line-selection breeding for variation of nitrogen content of wheat was made by R. W. Thatcher (79).

The composition of the maize crop was investigated by Jones and Huston (80) at various stages of growth corresponding to a time at which the crop would be used for practical purposes, such as soiling, ensilage and grain production. The object in view was the establishment of a plan for maintaining fertility by obtaining data concerning the amount of plant food removed by the maize crop.

Pingree (81) investigated the influence of nitrogenous, phosphatic and potassic fertilizers upon the percentage of nitrogen and mineral constituents of the oat plant in an attempt to ascertain to some degree the most productive and economical fertilizer material to give the best returns both in crop yield and amounts of plant food taken from the soil.

factors was the source of the soil acidity and the formation of leafmold. An important source of soil acidity is decaying leaves, and upon recently cleared timber lands farmers have found that only acid tolerant crops, such as rye, buckwheat and potatoes thrive, while later different varieties requiring a more alkaline condition grow well. Coville asks the question: "What is this peculiarity of forest leaves by which they make the soil at one time acid, at another alkaline?" Freshly fallen leaves, when moist, begin to decay and the acid radicals are leached out and thus produce soil acidity and when a certain degree of acidity has been reached decay ceases. If the soil is strongly alkaline, the acids leached are neutralized and decay continues until the soil again becomes acid. In many strongly alkaline soils leaf decay takes place very quickly while in acid soils many years are required before the leaf litter is all decomposed. After leaves have sufficiently decayed the leaf mold shows an alkaline reaction which is due to the large amount of lime in the composition of the leaves. When this stage is reached the soil becomes alkaline and ~~then~~ crops which require an alkaline soil can be produced. The change from acidity to alkalinity is often hastened by microorganisms capable of developing alkaline substances. Leaves from various species of trees require different lengths of time for their decay to reach the alkaline stage, as for example the silver maple leaves reach an alkaline state within a year, while many years are required for pine needles to attain this stage.

Gueymard (83) in 1863 undertook a series of experiments among the farmers in France in order to bring about a conservation of all manurial material. In his investigations with the fertilizer content of practically all forms of vegetation Gueymard showed the amount of valuable material which could be saved and advised all agriculturists to use it as a manure for their vineyards and farms. To increase their value such substances should be used as a bedding for animals and then be mixed with other manures and plowed in; or the leaves may be made into an ordinary compost allowing it to decompose before plowing in. Gueymard further concluded that they were valuable also as a source of organic matter and aided in improving the physical conditions of the soil.

The researches of J. Schröder (84) concerned the nitrogen content in forest trees and also in the under litter of leaves. The nitrogen and ash requirements of the forest trees, according to this author, were supplied by the leaves which fell about the trees and hence the importance of not removing the litter in the forest which was practiced in some places.

In 1881 Emmerling, Loges and Emeis (85), working together upon the manurial value of freshly fallen tree leaves, found them to have the following composition and value. All results are figured upon a 17.5% moisture basis and the manurial units are obtained by multiplying the percent of nitrogen by 5; percent of phosphoric acid by 2, and percent of potash by 1, adding the results and multiplying by 10 pfennigs (2.5 cents).

The value as indicated is recorded on the basis of 1 mark equals 23.8 cents.

Name of tree	% N	% P_2O_5	% K_2O	M.U.	Max. value per 110 lbs.
Grey poplar	1.52	.31	.92	9.14	$ .218
White willow	2.21	.44	1.25	13.20	.314
Silver poplar	1.65	.33	1.26	10.20	.242
Carpin betulus	1.00	.16	.31	5.60	.133
Silver birch	.67	.067	.270	3.70	.088
Maple	.84	.14	.80	5.30	.126
Red alder	2.47	.15	.22	12.90	.307
Oak	.93	.13	.42	5.30	.126
Red beech	.87	.17	.39	5.10	.121

Andre (86) sought to ascertain the amounts of nitrogen, phosphoric acid and potash which was returned to the soil from chestnut leaves and with what rate these substances diffused into the soil. Under natural conditions the leaves fall to the ground in the autumn, where they are subject to washing by rains and the action of insects and micro-organisms, thereby making available the nitrogen from the proteins, the phosphoric acid from mineral and organic phosphorus compounds, and the potash from salts of organic acids. Analyses were made upon chestnut leaves collected in the autumn and also upon leaves which had wintered on the ground for one season. A loss in the leaves collected in the spring was found amounting to 7.5% nitrogen, 67.4% phosphorus (calculated as H_3PO_4), and 87.7 potassium. Dead leaves after wintering in piles on the ground contain about twice as much nitrogen and the same amount of phosphoric acid (H_3PO_4) as a good farm manure, but the potassium is almost entirely lacking. The form in which the nitrogen occurs in the dead leaves is not so readily nitrified as that which occurs in a good farm manure. The potassium is the most diffusible element, practically all of the potassium diffusing into the sod after one winter. The phosphorus diffuses much less rapidly than the potassium, but a great deal more than the nitrogen. Thus the fertilizing materials in dead leaves return to the soil at a very unequal rate of speed. The nitrogen evidently exists in the leaf as protein which does not readily hydrolyze, thereby diffusing into the soil at a much lower rate than the other substances.

3. Experimental Results of the Investigations.

Collection and Preparation of Samples.

The leaves of three common New England trees, - the chestnut (Castanea Dentata), the sugar maple (Acer saccharum), and the white oak (Quercus alba) - were gathered in the fall, slightly previous to the time of changing color, from the highest branches of the tree and also from the lowest branches. Samples were selected from the above mentioned species which were growing upon three very different soil types, namely, Suffield clay, Holyoke stony loam (Mt. Pleasant near college orchard), and Wethersfield loam (86) (Sugar Loaf). In each case leaves were taken only from trees which appeared healthy, showed good growth, and were in such a situation as to enable the various organs to carry on their normal functions of life. Trees of about the same age and height as nearly as could be estimated were selected for this investigation. The leaves were picked from the branches, dried in the air, and then in a hot air oven at a temperature of about 70° C., after which they were finely ground, mixed thoroughly, and stored in sealed bottles.

Methods of Analysis.

The phosphoric acid (P_2O_5) was determined gravimetrically as magnesium pyrophosphate; the potash (K_2O) was determined gravimetrically as potassium chloroplatinate, and the nitrogen content of the leaves was determined by the Kjeldahl method modified to include the nitrogen of nitrates.

The several methods employed may be found in Bulletin No. 107 (87) (Revised 1912), Bureau of Chemistry, United States Department of Agriculture.

Characteristics of the Soil Types (88).

Suffield clay consists of from four to eight inches of heavy dark-drab clay loam resting on a heavy, tenacious gray-drab clay, which extends to a depth of twenty, and in some instances seventy-five feet. It is an unimportant agricultural soil of small extent. It is of deep lake origin, and while appearing very heavy and tenacious, it is largely composed of silt, probably of the finer grades. The type is cold and wet and is difficult to cultivate. The subsoil is very resistant to the development of plant roots, and all crops make meager growth. It is best utilized in the production of grass. The area upon which the trees under investigation grew occurred about a mile west of Amherst.

The soil of the Holyoke stony loam is a dark yellow or brown silty loam, from seven to twelve inches deep. The subsoil ranges from a moderately heavy yellow sandy loam to a heavy loam, with the sandier phase more abundant. The type is very stony thruout and contains pebbles and bowlders of angular shape. The soil in general is of moderate fertility. Grain and grass crops give good returns, and it is also suitable for grazing. This soil is very well adapted to the growth of apples, grapes and other fruits. The trees under observation grow on an area of this soil just west of the Massachusetts Agricultural College orchard.

The Wethersfield loam (formerly called Triassic stony loam) is a reddish to red brown silty loam, with a depth of fourteen inches, resting on a medium heavy sandy loam of reddish color three feet in depth. The material ranges from a sandy loam to a heavy silty loam which has a darker red color. Both soil and subsoil contain large numbers of angular bowlders of all sizes up to several feet in diameter, and the greater portion of these consist of the red and brown sandstone of the Triassic period. The prevailing red color is due to the presence of compounds of iron. This soil is best adapted to the growth of grains and small fruits, and is also well adapted to pasture lands. The trees under observation grew on an area on the east side of Mt. Sugar Loaf.

Variations in Spring and Fall Leaves.

TABLE I.

Species of leaves	Date of collection	Per cent Nitrogen (Dry basis)	Per cent P_2O_5 (Dry basis)	Per cent K_2O (Dry basis)	Remarks
Maple	9-20-13	2.126	1.031	1.014	Bottom portion of tree
"	"	2.110	1.123	1.193	Top " " "
"	5-22-14	3.201	.9303	1.614	Bottom " " "
"	"	3.483	1.079	1.834	Top " " "
Chestnut	9-24-13	2.438	1.162	.9817	Bottom " " "
"	6-1-14	2.959	1.024	1.450	" " " "
"	9-24-13	2.106	.9428	1.017	Top " " "
"	6-1-14	2.660	.9530	1.747	" " " "
Oak	9-26-13	2.475	.9634	1.007	Bottom " " "
"	6-5-14	3.175	1.048	1.581	" " " "
"	9-26-13	2.453	1.091	.9687	Top " " "
"	6-5-14	3.460	.9399	1.519	" " " "

Summary of Table I.

The nitrogen content of the leaves removed in the spring from the chestnut, oak, and maple shows a marked increase over the results obtained from the leaves removed from the same trees the preceding fall. The higher amount in the spring leaves occurs in both portions of the tree, although the leaves taken from the upper part of the tree show a greater increase. Since the leaves at the top of the tree are subject to a greater loss of water by evaporation and are attached to a younger growth of wood than the leaves at the bottom of the tree, undoubtedly the demands upon the tree sap are much greater at the top, thereby resulting in the migration of a greater supply of mineral matter from the soil to the higher portions of the tree. The leaves of the maple show the greatest variations, while the chestnut leaves show the least increase in the spring leaves as compared with those of the fall.

The potash content shews the same characteristic variations as that of nitrogen, with the exception that the oak leaves show the least increase in the spring.

The phosphoric acid content does not show the same variations as that of nitrogen and potash, but seems to vary with the species of tree and also the section of the tree from which the leaves were obtained. The leaves removed from the maple, the lower portion of the chestnut and the top portion of the oak have an increased phosphoric acid content in the fall leaves over those collected in the spring. The greater percentage content in the spring leaves collected from the top portion of the chestnut and the lower portion of the oak is so small that undoubtedly the spring leaves show a lower amount of phosphoric acid than the leaves of the preceding fall. The variations, however, are very small in all cases and the demands of the seeds and flowers of these trees for phosphoric acid probably causes, to a very great extent, these differences.

These results also indicate that a loss of mineral matter occurs with the advance of the season, regardless of the age of the tree.

Variations as Affected by Different Soil Types.

In view of the fact that various types of soil have an influence upon the composition of plants, leaves were removed from trees growing upon three typical Connecticut Valley soils already described. In Table II are the results of the analyses of the leaves of the maple, chestnut, and oak grown upon these three soil types.

TABLE II.

Species of leaves	Soil type	Per cent Nitrogen (Dry basis)	Per cent P_2O_5 (Dry basis)	Per cent K_2O (Dry basis)	Remarks
Maple	Suffield clay	1.379	.4948	.8555	Bottom portion of tree
"	" "	1.446	.6305	.8837	Top " " "
"	Holyoke stony loam	2.126	1.031	1.014	Bottom " " "
"	" " "	2.110	1.123	1.193	Top " " "
"	Wethersfield loam	1.907	---	.7249	Bottom " " "
"	" "	1.420	1.056	1.007	Top " " "
Chestnut	Suffield clay	1.954	.6992	1.489	Bottom " " "
"	" "	1.930	.6852	1.221	Top " " "
"	Holyoke stony loam	2.438	1.162	.9917	Bottom " " "
"	" " "	2.106	.9428	1.017	Top " " "
"	Wethersfield loam	2.798	1.233	1.460	Bottom " " "
"	" "	2.991	1.405	1.343	Top " " "
Oak	Suffield clay	2.079	.5188	1.022	Bottom " " "
"	" "	2.097	.6479	1.325	Top " " "
"	Holyoke stony loam	2.475	.9634	1.007	Bottom " " "
"	" " "	2.453	1.091	.9687	Top " " "
"	Wethersfield loam	2.044	.7295	1.182	Bottom " " "
"	" "	2.255	.9389	1.280	Top " " "

From the above table it is evident that the highest content of nitrogen, phosphoric acid and potash in the case of the maple leaves occur in those collected from trees growing upon the Holyoke stony loam.

The same is true of the oak leaves except that the potash content was highest in the leaves taken from trees grown upon Wethersfield loam.

The leaves of the chestnut show their highest amount in those removed from trees growing upon Wethersfield loam.

The lowest amounts of nitrogen and phosphoric acid occur in the leaves of all three trees grown upon the Suffield clay. The potash content was lowest in the case of the maple leaves from the Wethersfield loam and with the chestnut and oak from trees grown upon Holyoke stony loam. A summary of the highest and lowest contents of these elements may be brought out clearer by a table. The legend as used by the United States Department of Agriculture, Bureau of Soils, will represent the soil types, and they are as follows: Suffield clay, Sc; Holyoke stony loam, Hs, and Wethersfield loam, Ts.

Variation in Nitrogen, Phosphoric Acid and Potash Content with the Soil Type.

TABLE III.

Species of leaves	Highest am't of Nitrogen	Lowest am't of Nitrogen	Highest am't of P_2O_5	Lowest am't of P_2O_5	Highest am't of K_2O	Lowest am't of K_2O
Chestnut	Hs	Sc	Ts	Sc	Ts	Hs
Oak	Ts	Sc	Hs	Sc	Ts	Hs
Maple	Hs	Sc	Hs	Sc	Hs	Ts

Variations in the Composition of the Leaves taken from the Upper and Lower Branches of the Maple, Chestnut and Oak Trees.

For the purpose of determining the effect of the relative distances of the leaves from the soil on their composition, leaves were removed from the upper and lower branches of the trees.

The highest content of nitrogen, phosphoric acid and potash in the respective leaves will be inserted under the appropriate heading with the legend of the soil type upon which the trees grew. For example, the highest content of nitrogen in the leaves removed from the maple tree growing upon Suffield clay occurred in those leaves taken from the upper branches. All results are upon leaves collected in the fall of the year.

TABLE IV.

Species of leaves	Highest content of Nitrogen in the leaves taken from		Highest content of P_2O_5 in leaves taken from		Highest content of K_2O in leaves taken from	
	Upper branches	Lower branches	Upper	Lower	Upper	Lower
Maple	Sc		Sc		Sc	
"		Hs	Hs		Hs	
"	Ts				Ts	
Chestnut		Sc		Sc		Sc
"		Hs		He	Hs	
"	Ts		Ts			Ts
Oak	Sc		Sc		Sc	
"		Hs	Hs			Hs
"	Ts		Ts		Ts	

Summary of Table IV.

The highest content of nitrogen, phosphoric acid and potash occurs in the leaves taken from the upper branches of the maple tree grown upon all three soil types, with one exception.

The highest content of nitrogen in the maple leaves from the Holyoke stony loam occurs in those samples removed from the lower branches.

The leaves taken from the chestnut tree grown upon Suffield clay show their highest content of nitrogen, phosphoric acid and potash in the leaves removed from the lower branches. The nitrogen and phosphoric acid is highest in the leaves from the lower branches, while potash is the highest in the upper leaves on the chestnut tree grown upon Holyoke stony loam. The leaves removed from the upper branches of the chestnut tree grown upon the Wethersfield loam exhibit the highest content of nitrogen and phosphoric acid, while potash is highest in the lower leaves of the same tree.

The upper leaves in the case of the oak show the highest content of nitrogen, phosphoric acid and potash in those leaves removed from trees grown upon Suffield clay and Wethersfield loam. The nitrogen and potash are highest in the leaves removed from the lower branches of the oak tree growing upon the Holyoke stony loam, while the phosphoric acid shows the highest content in the upper leaves of the same tree.

The highest content of nitrogen, phosphoric acid and potash occurs in the majority of cases in the leaves removed from the upper branches of the tree. The exceptions may be due to rainfall, sunlight, temperature, flow of sap in tree, and physiological functions going on within the leaves at this time of the year when the fruit and seeds are maturing which results in a drain upon the constituents of the leaf.

Variations in the Composition of Leaves Removed from the Upper and Lower Branches of the Same Trees in the Fall and Spring of the Year.

In view of the fact that the time of the year may have an influence upon the composition of the leavee removed from the upper and lower branches of trees, analyses were undertaken to show such variations as may occur. In Table V the highest content of nitrogen, phosphoric acid and potash are indicated by inserting the soil legend (in this case Hs) in the proper column.

TABLE V.

Species of leaves	Highest content of Nitrogen in the leaves taken from		Highest content of Phosphoric acid in leaves taken from		Highest content of Potash in the leaves taken from	
	The upper branches	The lower branches	The upper branches	The lower branches	The upper branches	The lower branches
Maple (Fall)		Hs+	Hs		Hs	
" (Spring)	Hs		Hs		Hs	
Chestnut (Fall)		Hs		Hs	Hs	
" (Spring)		Hs		Hs	Hs	
Oak (Fall)		Hs+	Hs			Hs
" (Spring)	Hs		Hs			Hs

+ The increased content of nitrogen in the lower leaves of the oak and maple collected in the fall over the content in the upper leaves is so small that the results may change as the various factors enter into the processes of the leaf.

Summary of Table V.

The maple leavee collected from the same tree in the fall and spring show their higheet content of nitrogen, phosphoric acid and potash when taken from the upper branches, with one exception, which is so small that it may be considered as due to some error in collecting or preparing that particular sample.

The leaves of the lower branches of the chestnut tree show the highest content of nitrogen and phosphoric acid in both fall and spring, while the potash is highest in the leaves removed from the upper branches.

The lower leaves of the oak are highest in potash in both fall and spring, while phosphoric acid is highest in the upper leaves for both seasons of the year. In the case of nitrogen the fall leaves taken from the lower branches of the oak are highest in this constituent, while in the spring the leaves from the upper branches exhibit the highest amount of nitrogen.

These variations in the composition of the leaves from the upper and lower branches, especially in the case of the spring and fall leaves, may be due to a large extent to the relative amount of sap flowing from the roots to the other organs of the tree and also the return of matter from the assimilative organs to the branches, trunk and roots of the tree. O. M. Shedd (90) in an investigation upon the mineral composition of sap in the sugar maple found that the composition of the sap varied considerably when collected at the same point on the tree during two successive years just after the sap flow had commenced.

In view of this fact, the variations which are noted in Tables IV and V may be influenced to a large extent by the upward sap flow in the spring and to a backflow of sap in the fall of the year. Another factor which may influence this variable composition is the demand of the fruit and seeds for these constituents for their proper development.

Estimation of the Value of Tree Leaves as a Fertilizer.

As the function of tree leaves is primarily the elaboration of crude inorganic materials taken from the air and soil into the various compounds for the nutrition and support of the tree and its different organs, it is natural that these specific organs would contain much of the chief plant food materials. Their use as a source of organic matter and as plant food has long been recognized, and in the early agricultural history of Europe leaves and other forms of litter were used to a large extent for their fertilizer value. An early practice in Europe was the complete raking of all woodlands for the fallen leaves which were used on the farms as a manure. The practice became so extensive that the foresters in many of the large forests in Germany and Austria forbade the raking of their woodlands, because of the loss of this valuable material as a fertilizer for the trees grown upon the land. The foresters assigned the decreasing rate of growth of the forests to this constant raking by the farmers.

Some fifty years ago, here in New England many farmers gathered all the available leaves and used them as bedding for their animals and as an absorbent in barns, after which they were composted and then spread upon the farm. On many of the farms in the Connecticut Valley the same practice is still in use. Many of the leaves about the college grounds are gathered in the fall, used as bedding for horses, composted with other manures for a period of two years or so, and then applied to the soils in the greenhouses.

As the cost of labor for collecting and handling the leaves would be large, it would be inadvisable for the farmer to spend his time in this way. As an aid in promoting the growth of trees in woodlands, the leaves have a distinct value and should be allowed to remain where they fall.

The value of leaves as a source of organic matter can hardly be estimated by any cash value. The humus added to the soil in this way undoubtedly amounts to a great deal, and aids in the improvement of the physical condition of the soil; i.e., improves texture, aeration, water holding capacity, and capillarity. This organic matter in all probability serves as favorable food for the various micro-organisms in the soil, and as such should be considered as a valuable asset. It is probable, however, that the usual cost of collection and preparation would exceed their physical and chemical value.

There is one disadvantage in the use of freshly fallen leaves upon the soil, and that is the production of acid. Crops which are acid tolerant will not be injured by this condition. On the other hand, crops which require an alkaline or neutral soil will be adversely affected if a heavy application of freshly fallen leaves has been incorporated into the soil. All favorable micro-organism action in the soil ceases upon soils with an excess of acid, and unless plenty of lime has been added to produce an alkaline condition, ammonification and nitrification does not take place. As an example of the acidity of freshly fallen leaves, the following table will show the amount in tons of ground limestone required per acre to neutralize a compact layer of leaves six inches in depth estimated to weigh when dry 500,000 pounds.

TABLE VI[1]

Acidity of freshly fallen leaves in terms of lime requirement per acre.

Species of leaves	Acidity Tons	Species of leaves	Acidity Tons
White oak	25	Sugar maple	22
Red oak	16	Tulip tree	14
Silver maple	22	Virginia pine	22

In other words, it requires 25 tons of ground limestone to neutralize 250 tons of freshly fallen leaves of the white oak tree. In view of this fact, it is advisable to accumulate the various leaves and compost the entire mass of organic matter. The leaves are allowed to decompose for various periods of time, and when they have reached the alkaline stage they may be used in hot-beds, greenhouses, or on the field. During the decomposition there is undoubtedly some of the fertilizing material lost by volatization and leaching. This slight loss is offset to some extent by the favorable alkaline condition of the leaves and also by the large amount of alkali matter added to the soil.

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[1] Table taken from Bulletin No. 6, U.S. Dept. Agriculture, Bureau of Plant Industry, by F. V. Coville.

The manurial value as estimated in this investigation will be somewhat higher than in the case of fallen leaves, because they were picked from the branches on the different trees shortly before the coloring and before the complete return to the trunk of the tree of a certain amount of the mineral matter. The manurial units were obtained by multiplying the percent of N by 2.5; the percent potash by 1; the percent phosphoric acid by 1; then adding the results. The commercial value[1] estimated upon raw material like leaves was 10 cents per pound for nitrogen, 4 cents per pound for potash, and 4 cents per pound for phosphoric acid[2]. The value per ton of leaves was then obtained by multiplying the manurial units by 4 cents and that result by 20. In order to draw a comparison, the analytical results following have all been reduced to the dry basis. The results are expressed upon leaves in dry condition and also on those with a 20% moisture content.

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[1] The commercial values were figured upon materials before the war and not upon the values now existing.

[2] Cash prices of materials obtained from Henri D. Haskins, in charge of Fertilizer Section, Massachusetts Agricultural Experiment Station.

Estimated Manurial Value of Leaves.

TABLE VII.

Species of leaves	Time of collection	Soil type[+]	Height of leaves from top of soil	Per cent Nitrogen Dry basis	Per cent P_2O_5 Dry basis	Per cent K_2O Dry basis	Manurial Units	Estimated value per ton of dry matter	Estimated value per ton on a 20% moisture basis
Maple	9-16-13	Sc	15 ft.	1.379	.4948	.8555	4.79	$3.83	$3.06
"	"	"	45 "	1.446	.6305	.8837	5.11	4.09	3.27
Chestnut	"	"	10 "	1.954	.6992	1.489	7.07	5.65	4.52
"	"	"	50 "	1.930	.6852	1.221	6.72	5.37	4.29
Oak	9-13-13	"	12 "	2.079	.5182	1.022	6.71	5.35	4.29
"	"	"	40 "	2.097	.6479	1.325	7.19	5.74	4.59
Maple	9-20-13	Hs	8 "	2.126	1.031	1.014	7.34	5.87	4.69
"	"	"	50 "	2.110	1.123	1.193	7.59	6.07	4.85
Chestnut	9-24-13	"	10 "	2.438	1.162	.9917	8.25	6.60	5.28
"	"	"	50 "	2.106	.9428	1.017	7.21	5.76	4.60
Oak	9-26-13	"	5 "	2.475	.9634	1.007	8.13	6.50	5.20
"	"	"	50 "	2.453	1.091	.9687	8.18	6.54	5.23
Maple	9-28-13	Ts	8 "	1.907		.7249			
"	"	"	50 "	1.420	1.056	1.007	5.61	4.48	3.58
Chestnut	"	"	8 "	2.798	1.333	1.460	9.66	7.72	6.17
"	"	"	50 "	2.991	1.405	1.343	10.20	8.16	6.52
Oak	"	"	10 "	2.044	.7295	1.182	7.01	5.60	4.48
"	"	"	40 "	2.255	.9389	1.280	7.84	6.27	5.01
Maple	5-22-14	Hs	8 "	3.201	.9303	1.614	10.54	8.43	6.74
"	"	"	50 "	3.483	1.079	1.834	11.61	9.28	7.40
Chestnut	6-1-14	"	10 "	2.959	1.024	1.450	9.87	7.89	6.31
"	"	"	50 "	2.660	.9530	1.747	9.34	7.47	5.97
Oak	6-5-14	"	5 "	3.175	1.048	1.581	10.55	8.44	6.75
"	"	"	50 "	3.460	.9399	1.519	11.11	8.88	7.10

[+] Soil types referred to are according to legend used by Bureau of Soils and are as follows: Sc, Suffield clay; Hs, Holyoke stony loam; Ts, Wethersfield loam.

The values given are figured simply upon the basis of the chief fertilizer constituents in the leaves and no attempt has been made to deduct the cost of handling or to determine the availability of these substances. Further investigations will be undertaken to ascertain the availability.

Summary of Table VII.

The leaves of the chestnut show the highest cash value, $6.52 per ton for leaves taken from the top branches of the tree.

The values for the spring leaves are much higher than the value of the fall leaves taken from the same tree. The results upon the spring leaves were obtained only for comparison.

CONCLUSIONS.

1. The leaves collected in the spring show a higher content of nitrogen and potash than those collected in the fall from the same trees.

2. The phosphoric acid content varies with the species of tree and also with the section of the tree from which the leaves were obtained.

3. The lowest amount of nitrogen and phosphoric acid occurred in those leaves collected from trees grown upon a clay soil. The highest content of nitrogen, phosphoric acid, and potash occurred in those leaves collected from trees grown upon the Holyoke stony loam and Wethersfield loam.

4. The leaves from the upper branches of the maple and oak have a higher content of nitrogen, phosphoric acid and

potash in the majority of cases than those taken from the lower branches. In the case of the chestnut the reverse appears to be true, the leaves from the lower branches having the larger amount of nitrogen, phosphoric acid and potash, with some exceptions, than those removed from the upper branches.

5. The estimated theoretical cash value of a ton of leaves calculated upon a 20 per cent moisture basis varies from $3.00 to $6.50, depending upon the kind of leaves and upon what portion of the tree they were grown.

6. The cost of collecting and handling would probably be greater than the value of the leaves, thus making it inadvisable in most cases for farmers to spend their time in this way.

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